

# Research On Fuzzy Pid Control System Of Temperatuer For Tertiary Air

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**Abstract.** The introduction of the AQC boiler has complex effects on the temperature of Tertiary air, traditional PID is difficult to achieve the effective control. Combined the method of the conventional PID with the fuzzy control theory, a fuzzy self-tuning PID controller is designed. Compared with traditional PID, results of simulation show that the fuzzy PID controller improves not only the adaptability and robustness of the system, but also the system's static and dynamic performance.

## Introduction

The heat of low temperature boiler comes from the Rotary Kiln's waste gas, the gas's temperature and flux will influence the process of cement production. The AQC boiler is located at the head of the Rotary Kiln. The heat source of the boiler comes from the Grate Cooler's waste gas, which is also the source of Tertiary air. Because of the introduction of the AQC boiler, the control of Tertiary air's temperature is more complicated [1]. In order to solve this problem, a fuzzy self-tuning PID controller is designed. Based on the fuzzy self-tuning control theory, the temperature's error  $e(t)$  and error rate of change  $e_c(t)$  are chosen as inputs. The values of PID parameters are given according to  $e(t)$  and  $e_c(t)$  in different time, so that there is a better control on the temperature of Tertiary air.

## Analysis of Control Object

**Technological Principle of Grate Cooler.** The clinker with the temperature of 1350°C flows from the Rotary kiln into the Grate cooler. In this process, clinker is cooled by high-pressure cold air that comes from the blowers below the Grate cooler [2]. The grate cooler can be divided into three parts: The clinker is quenched at high temperature zone, the waste air is the source of Secondary air and Tertiary air; Medium temperature zone is the recovery zone, waste air flow into the AQC boiler from this area; Low temperature zone has a further cooling of clinker.

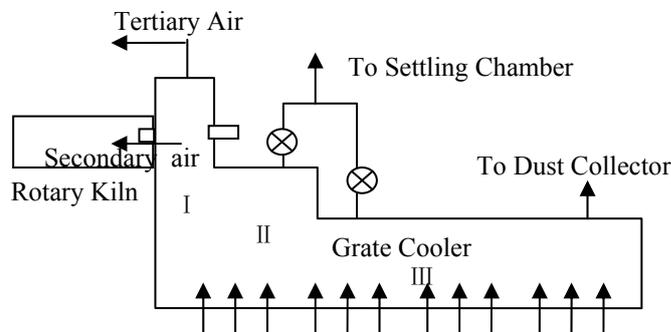


Figure. 1 Technological Principle

**Control Object.** Based on a specialized product line, the exports of high temperature air are located at medium temperature zone and low temperature zone. There are two valves to control the flux of the air. The former export is near to the high temperature zone. If the opening degree of the valve is too large, most of the hot air will flow into the AQC boiler, the temperature of Tertiary air will be decreased. Compared with the former export, the later export is far from the high temperature

zone, which has almost no influence on the temperature. According to the analysis, the valve of the former export is chosen as control object.

**Controller Design and Simulation**

The theoretical analysis and experimental results show that: The temperature of Tertiary air is an object with self-balance ability, which can be described as a second-order model with pure lags. After identification, it can be identified to a first-order model [3]. The transfer function can be described as:

$$G(s) = \frac{K \cdot e^{-\tau s}}{TS + 1} \tag{1}$$

The curve of the Tertiary air’s temperature is shown in Figure 2.

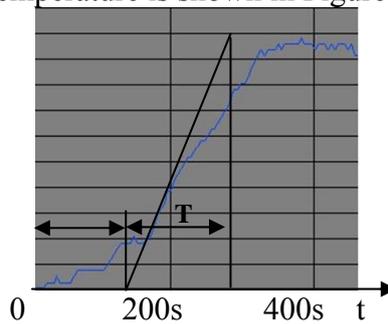


Figure. 2 Flying-Rising curve

We can get the parameters from flying-rising curve:  $\tau=135s, T=150s$ .

$$G(s) = \frac{1.25 \cdot e^{-135s}}{150S + 1} \tag{2}$$

**Design of Conventional PID Controller.** Set the temperature’s error  $e(t)$  as the input of the PID controller, set the former valve’s opening degree  $u(t)$  as output.

$$u(t) = K_p[e(t) + \frac{1}{T_i} \int_0^t e(t)dt + T_d \frac{de(t)}{dt}] \tag{3}$$

Using difference equation:

$$u(t) = K_p \{e(k) + \frac{T}{T_i} \sum_{i=1}^k e(i) + \frac{T_d}{T} [e(k) - e(k-1)]\} = K_p e(k) + K_i \sum_{i=1}^k e(i) + K_d de(k) \tag{4}$$

Parameters can be get from the transfer function:  $K=1.25, T=150s, \tau=136s$ .

According to the rule of Ziegler - Nichols parameter tuning [4]:

$$K_p=1.2T/\tau=1.33, T_i=2\tau=272s, T_d=0.5\tau=68s. K_i=K_p/T_i=0.00488, K_d=K_p T_d=90.44.$$

Create the PID controller in Simulink. The given temperature is 900 °C, the simulation result is shown below:

**Design of Fuzzy Controller.** The inputs of Fuzzy controller [5] are error  $e(t)$  and error rate of change  $e_c(t)$ , the output is the former valve’s opening degree  $u(t)$ . The range of the Tertiary air’s temperature is between 850 °C – 950 °C, the domain of  $e(t)$  is [-50,50], the domain of  $e_c(t)$  is [-2,2]. Fuzzy sets:  $E = \{-6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6\}$ ,  $E_C = \{-6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6\}$ . The domain of the valve’s opening degree is  $\{-10\%, 10\%\}$ , fuzzy sets  $U = \{-3, -2, -1, 0, 1, 2, 3\}$ .

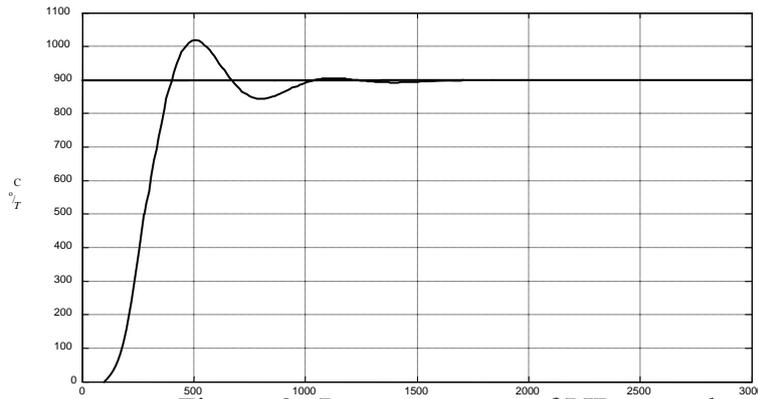


Figure 3 Response curve of PID control

The membership functions of variables are as follows:

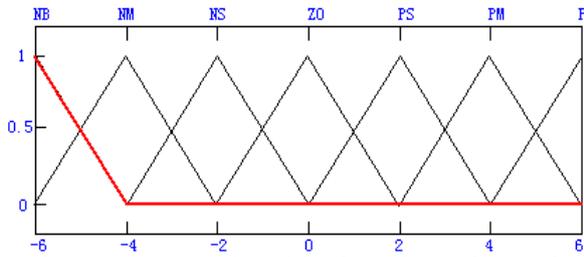


Figure 4 Membership function of E and Ec

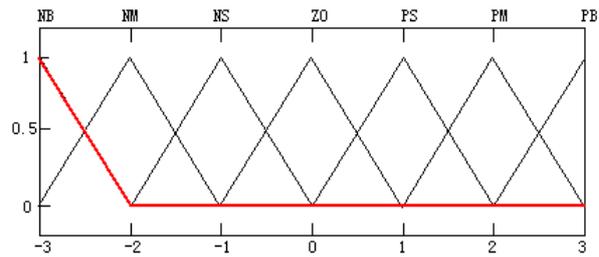


Figure 5 Membership function of U

Construct a fuzzy controller in MATLAB Fuzzy Logic Toolbox, control rules are expressed in the form of if-then. Figure below shows the simulation of the system by given a value of 900 °C. It can be seen from the figure that the stability of the system is enhanced, and the time of adjustment is reduced, but there is a steady- state error.

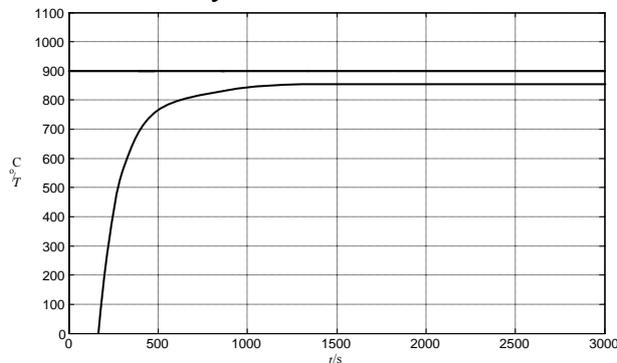


Figure 6 Response curve of Fuzzy control

Table 1 Temperature Control rules

E	Ec						
	PB	PM	PS	ZO	NS	NM	NB
PB	PB	PB	PB	PB	PM	ZO	ZO
PM	PB	PB	PB	PM	PS	ZO	ZO
PS	PM	PM	PM	PS	ZO	NS	NM
ZO	PM	PM	PS	ZO	NS	NM	NM
NS	PS	PS	ZO	NS	NM	NM	NM
NM	ZO	ZO	NS	NM	NB	NB	NB
NB	ZO	ZO	NM	NB	NB	NB	NB

**Design of Fuzzy PID Controller.** The fuzzy controller uses two-dimensional controller called Mamdani. Fuzzy control decision uses the Max-Min, the process of defuzzification uses the method of Centroid. Fuzzy control rules shown in the tables are used to modify the PID parameters [6]. With the estimates of  $e(t)$  and  $e_c(t)$ , we can adjust the PID parameters  $K_p, K_i, K_d$  as follows:

$$K_p = K'_p + \{E, EC\} K_p = K'_p + \Delta K_p \tag{5}$$

$$K_i = K'_i + \{E, EC\} K_i = K'_i + \Delta K_i \tag{6}$$

$$K_d = K'_d + \{E, EC\} K_d = K'_d + \Delta K_d \tag{7}$$

$K'_p = K_p = 1.33, K'_i = K_i = 0.00488, K'_d = K_d = 90.44$ . The fuzzy controller use  $e(t)$  and  $e_c(t)$  as inputs,  $\Delta K_p, \Delta K_i, \Delta K_d$  as outputs. The control rules are summarized as follows:

Table 2 Adjustment Control rule table of  $K_p$

Table 3 Adjustment Control rule table of  $K_i$

	Ec						
E	PB	PM	PS	ZO	NS	NM	NB
PB	NB	NB	NM	NM	NM	ZO	ZO
PM	NB	NM	NM	NM	PS	ZO	PS
PS	NM	NM	NS	NS	ZO	PS	PS
ZO	NM	NM	NS	ZO	PS	PM	PM
NS	NS	NS	ZO	PS	PM	PM	PM
NM	NS	ZO	PS	PS	PM	PB	PB
NB	ZO	ZO	PS	PM	PM	PB	PB

	Ec						
E	PB	PM	PS	ZO	NS	NM	NB
PB	PB	PB	PM	PM	PS	ZO	ZO
PM	PB	PB	PM	PS	PS	ZO	ZO
PS	PB	PM	PS	PS	ZO	NS	NM
ZO	PM	PM	PS	ZO	NS	NM	NM
NS	PS	PS	ZO	NS	NS	NM	NB
NM	ZO	ZO	NS	NS	NM	NB	NB
NB	ZO	ZO	NS	NM	NM	NB	NB

Table 4 Adjustment Control rule table of

	Ec						
E	PB	PM	PS	ZO	NS	NM	NB
PB	PB	PS	PS	PM	PM	PM	PB
PM	PB	PS	PS	PS	PS	ZO	PB
PS	ZO						
ZO	ZO	NS	NS	NS	NS	NS	ZO
NS	ZO	NS	NS	NM	NM	NS	ZO
NM	ZO	NS	NM	NM	NB	NS	PS
NB	PS	NM	NB	NB	NB	NS	PS

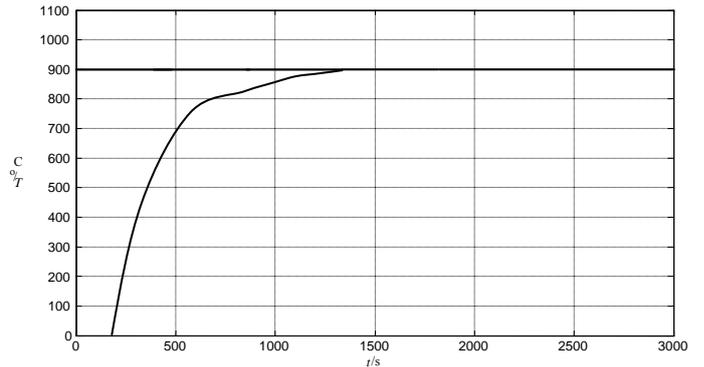


Figure. 7 Response curve of Fuzzy PID

As seen from the curve, overshoot  $\delta\% = 0$ , steady-state error  $e_{ss} = 0$ .

**Summary**

Fuzzy self-tuning PID controller has features of simple method and flexible adjustment. Simulation results show that the fuzzy PID controller has strong parameters self-tuning adaptive ability and better robustness.

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**References**

[1]Liu Tian zhen. Effects of Waste Heat Power Generation on Rotary Kiln and Mill System. Cement, Vol.5,May,2009,pp27-28.

[2]Zhang Kai, He Hui ning. Investigation and Engineering Practice of Heat Extracting from the Cement Kiln Cooler for Waste Heat Power Generation. Energy Conservation Technology, Vol.26, Nov.2008, pp 496-499.

[3]Liu Dang hui. System Identification Methods and Applications. National Defense Industry Press, July 2010.

[4] Huang You rui, Qu Li guo. Parameters Tuning of the PID Controller and Implementation. Science Press, Jan.2010.

[5]Zhang Wei guo. Fuzzy Control Theory and Applications. Northwestern Polytechnic University Press, July 2004.

[6]Li Jian, Wang Dong qing. Design of Fuzzy PID Controller and its Simulation Based on MATLAB, Industrial Control Computer, Vol.5, May,2011, pp:56-57.